National Aeronautics and Space Administration

ERA's open rotor studies including shielding for noise reduction

Environmentally Responsible Aviation Project

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Sub-Project Engineer for Propulsion

Additional system analysis provided by the Subsonic Fixed Wing Project

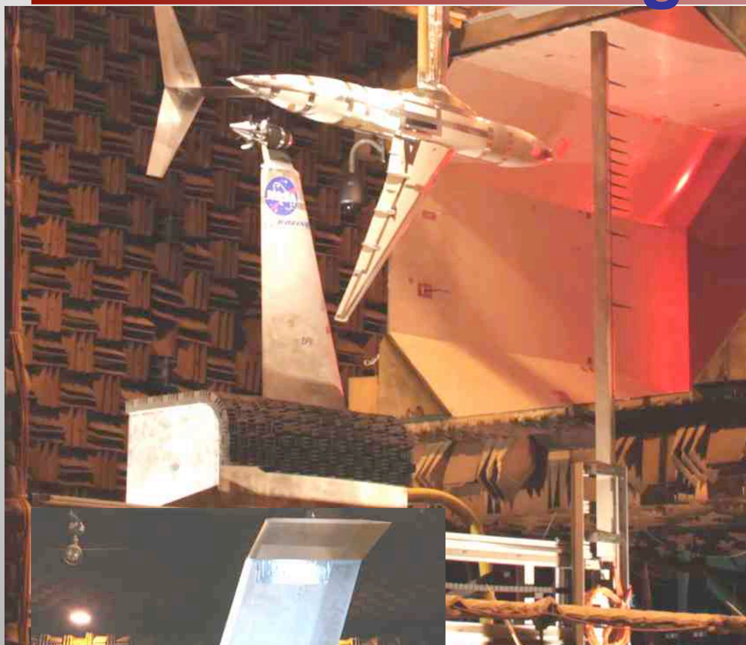
Progress Towards Open Rotor Propulsion Technology
Royal Aeronautical Society Headquarters
No. 4 Hamilton Place, London, UK
November 21, 2012

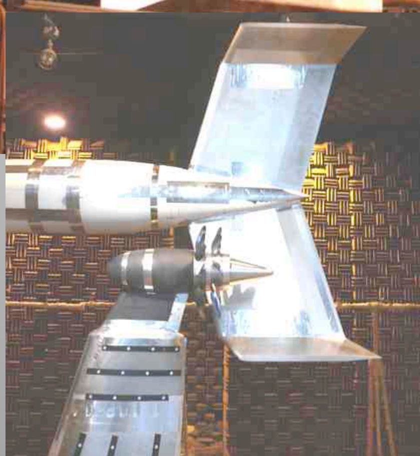
Outline

- NASA/Boeing PAA with an Open Rotor
- The GE/NASA/FAA Open Rotor Test Campaign
- Systems Analysis of an Advanced Single Aisle Aircraft
- The ERA Diagnostics Test at NASA Glenn
- Simplified shielding configurations
- Outlook

NASA/Boeing Open Rotor Propulsion Airframe Aeroacoustic Integration Effects Test in 2010

NASA/Boeing Open Rotor Propulsion Airframe Aeroacoustic Integration Effects Test in 2010





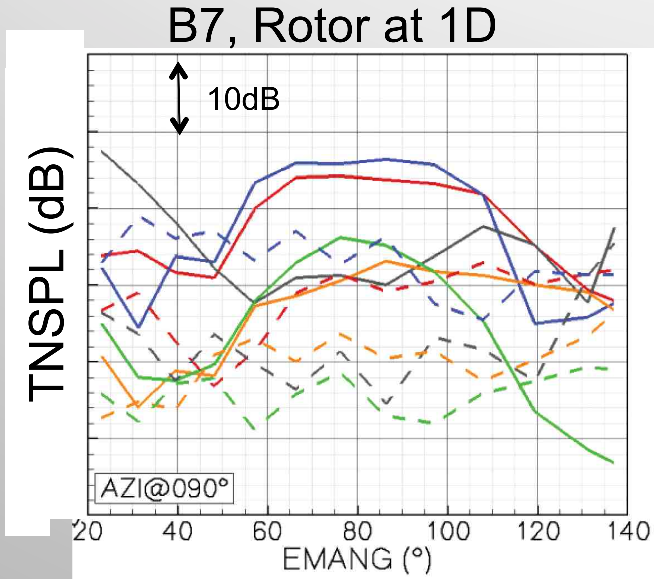
Heritage Eight by Eight F7/A7 Rotor

Conventional Airframe:
- U-tail and T-tail
- Multiple rotor/main wing positions
- Angle of attack
- Fuselage boundary layer variations
- Takeoff and Approach flaps

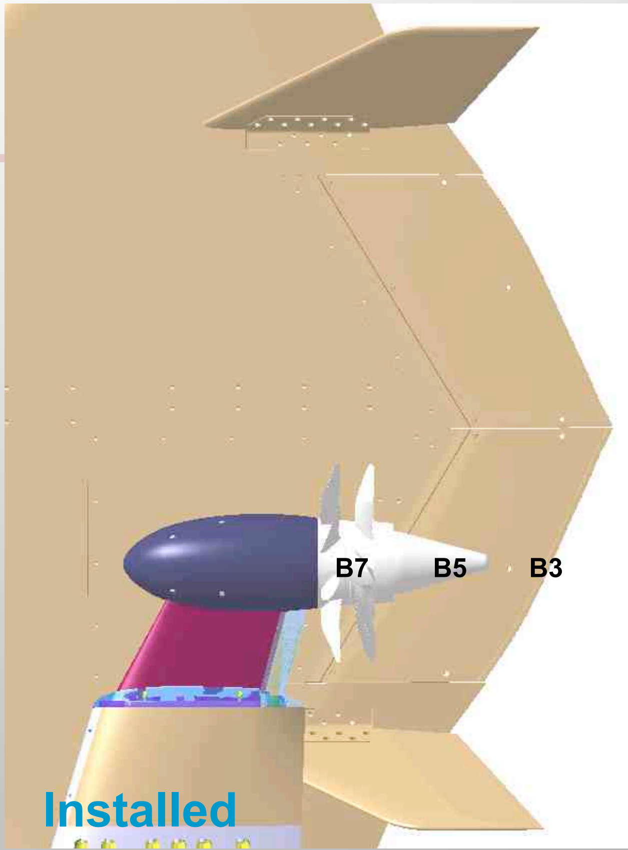
HWB Planform Model:
- Derived from a Boeing BWB Configuration
- NACA airfoil leading and trailing edges
- Vertical surface variations
- Elevon variations
- Instrumentation including surface unsteady pressures

Reference: Czech, M.J., and Thomas, R.H., "Experimental Studies of Open Rotor Installation Effects," presented at the AIAA 3rd Atmospheric and Space Environments Conference, June, 2011.

Shielding of Five Tones

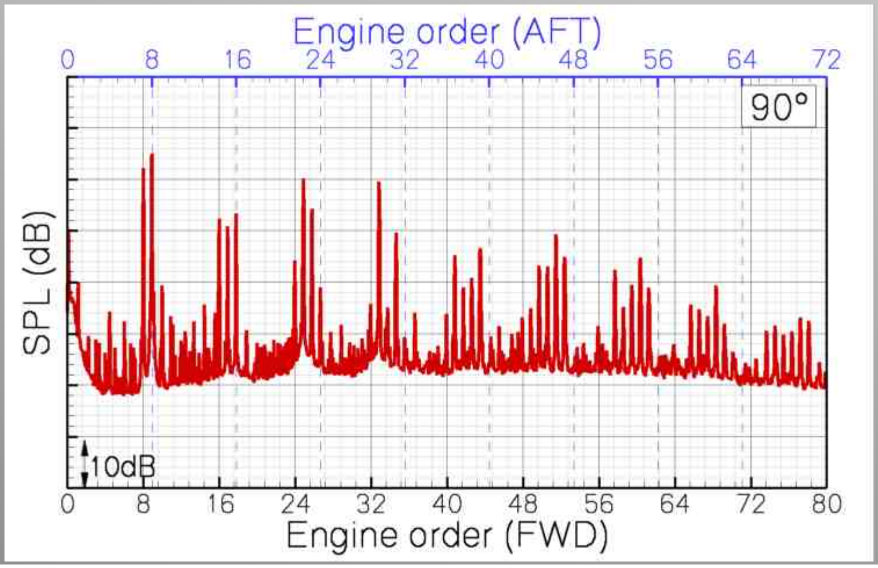


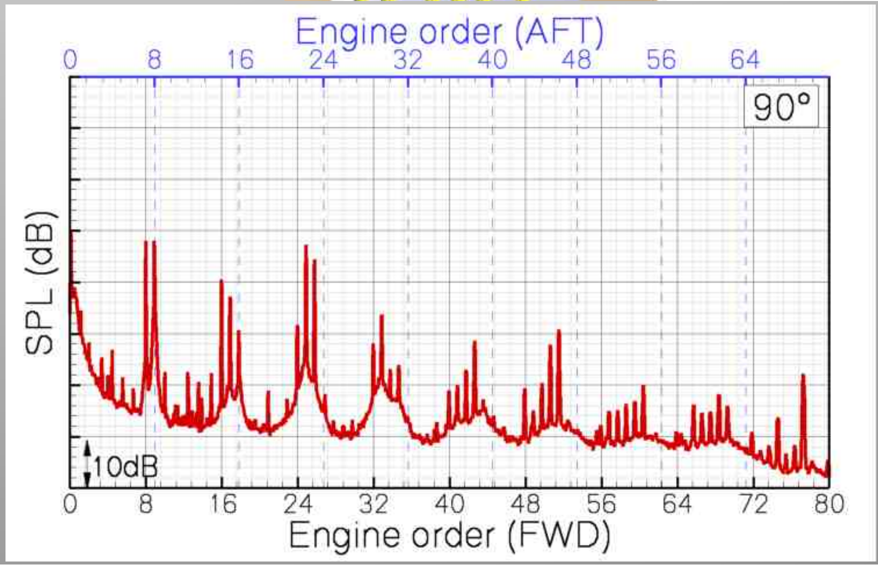
Solid Line is Isolated
Dashed Line is Shielded
Red = m(1,0)
Blue = m(0,1)
Black = m(1,1)
Orange = m(2,0)
Greeen = m(0,2)



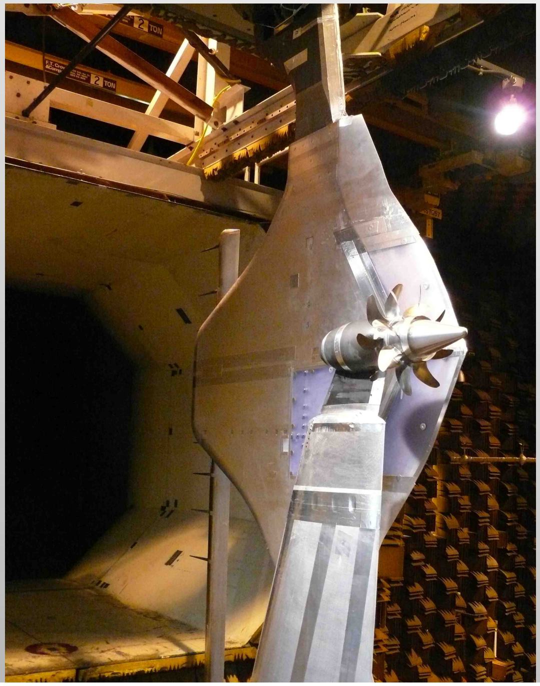
Isolated

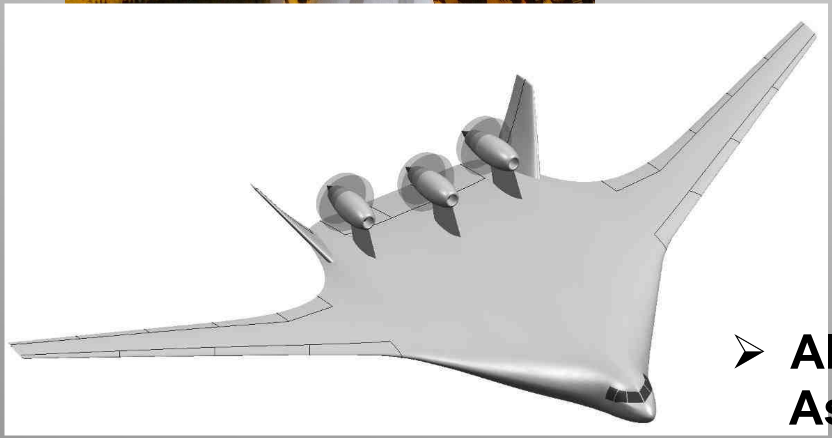
Installed





NASA HWB Open Rotor Noise Assessment





- NASA Glenn projection of best open rotor source levels in 2025

- NASA Langley/Boeing Experimental Data for Key Installation Effects Including:
  - rotor speed variation
  - wind tunnel Mach variation
  - rotor to airframe relative position, axial and vertical
  - off-center and centerline positions
  - inboard verticals, size and cant angle
  - elevon deflection

- Boeing Vehicle Model and a NASA Glenn Engine Model

- All Elements Combined in a NASA Noise Assessment of Open Rotor HWB (papers planned for 2013 Aeroacoustics Conference)

The GE/NASA/FAA Collaboration on Open Rotor Testing

- **Objective: Explore the design space for lower noise while maintaining the high propulsive efficiency from a counter-rotating open rotor system.**
- **Approach:** A low-noise open rotor system is being tested in collaboration with General Electric and CFM International, a 50/50 joint company between Snecma and GE. Candidate technologies for lower noise will be investigated. Installation effects such as pylon integration will be investigated in partnership with GE and the FAA.

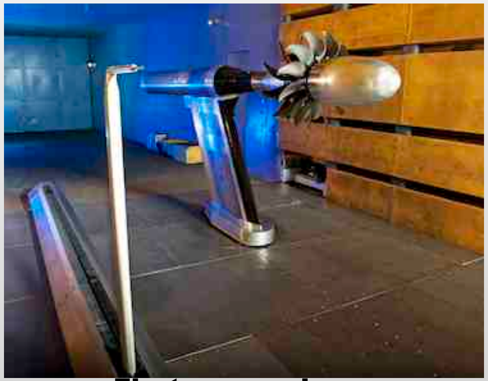
Gen-1 Blade Sets (NASA/GE)
- Historical Baseline
- Modern Baseline
- 2 GE Advanced Designs
- 2 Snecma Designs

Gen-2 Blade Sets (NASA/FAA/GE)
- 6 GE Advanced Designs
- Pylon wake mitigation

Historical Baseline
Blade Set
12 x 10 blade count

History (1/3)

Drive rig rehab and installation



First research run.
Oct 28

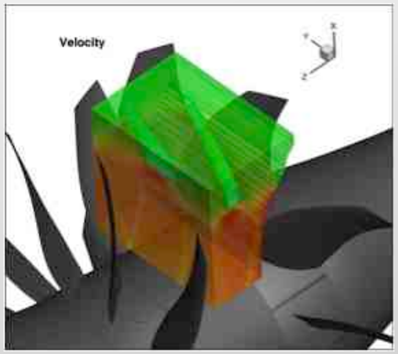
Airframer entry 1 start
Dec 14

2009				
Aug	Sep	Oct	Nov	Dec

Drive rig checkout.
Sep 24 – Oct 27

Linear array checkout.
Dec 7-11

History (2/3)



GE/Airbus test complete.
Feb 12

GE/Boeing test.
Apr 5 – 28.

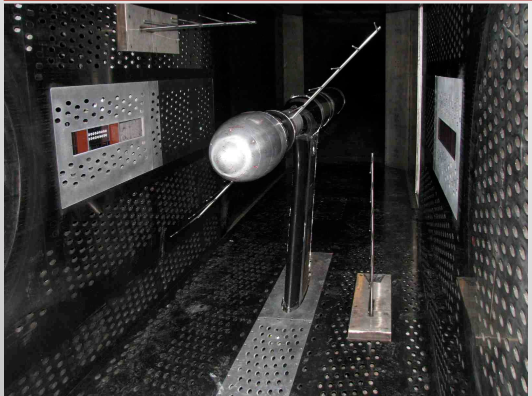
ERA Diagnostics Test.
Jul 19 – Sep 7

2010											
Jan	**Feb**	**Mar**	**Apr**	**May**	**Jun**	**Jul**	**Aug**	**Sep**	**Oct**	**Nov**	**Dec**

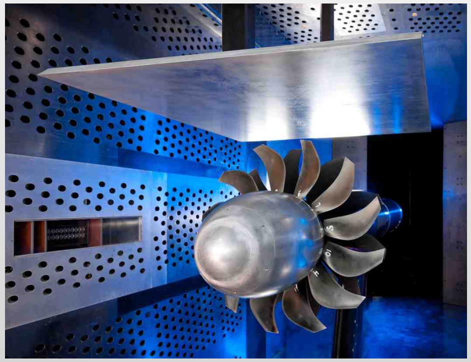
Drive rig muffler implementation.

Open Rotor Install
In the 8x6

History (3/3)



8x6 Tare Runs
Feb 9



Gen-1 8x6 Test
Feb 28 – Aug 25

Gen-2 8x6 Test
Aug 26 – Sep 9

Gen-2 9x15 Test
Nov 10 – Jan 19

2011

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec

Jan. 19, 2012
End of Gen-2 Test

Systems Analysis of an Advanced Single Aisle Aircraft

NASA Study Results – Fuel Burn vs. Noise

NASA modern airplane:
15% structural weight reduction from composites
5000 psi hydraulic systems
1% drag reduction from drag cleanup and variable trailing edge
Open rotor version has +2100lbs (953 kg) weight penalty

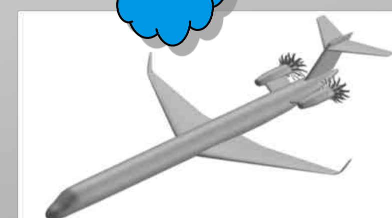
Advanced UHB Turbofan
Fuel burn: 27%
Noise: 25 dB cum margin to CH4

N+1 Tech
UHB TF
BPR ~14

NASA modern airplane
162 pax, 3250nm mission
Cruise M= 0.78, 35kft (FL350)
Rear mount Turbofan

Open Rotor (modern blade set)
Fuel burn: 36%
Noise: 13 dB cum margin to CH4

N+1 Tech
Open Rotor
BPR >30



NASA modern airplane
162 pax, 3250nm mission
Cruise M= 0.78, 35kft (FL350)
Rear mount Open Rotor

Guynn, M., Berton, J., Hendricks, E., Tong, M., Haller, W., & Thurman, D. (2011). "Initial Assessment of Open Rotor Propulsion Applied to an Advanced Single-Aisle Aircraft," 10th AIAA Aviation Technology, Integration, and Operations (ATIO) Conference, AIAA-2011-7058. Virginia Beach, VA.

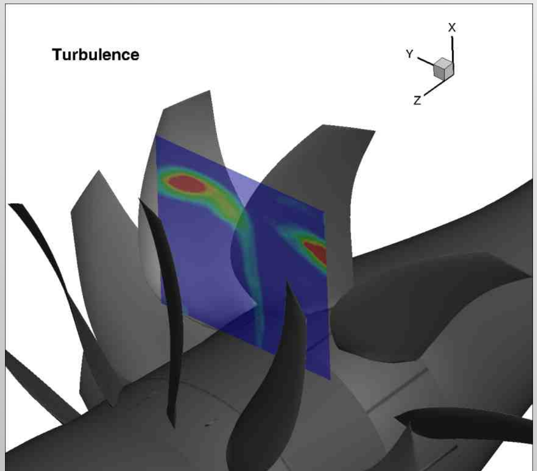
1998 technology reference vehicle
162 pax, 3250nm mission

Noise Margin

% Fuel Burn Benefit

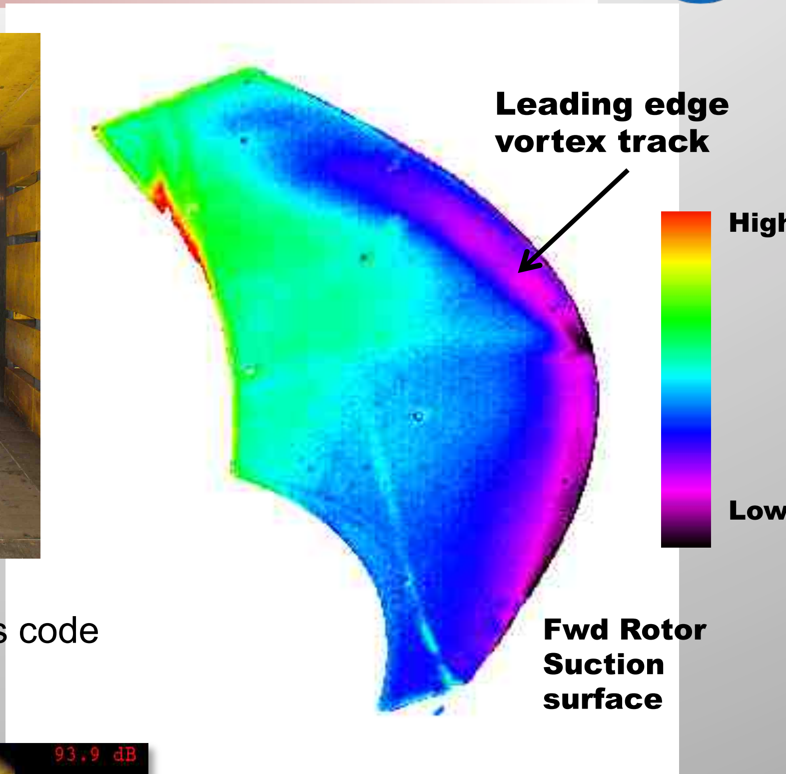
The ERA Diagnostics Test at NASA Glenn

ERA Diagnostics:
Detailed Historical Baseline flowfield measurements



The 3D **PIV** measurements provide a wealth of information about the blade wakes and vortex track.

A canonical shielding configuration provides code validation data.

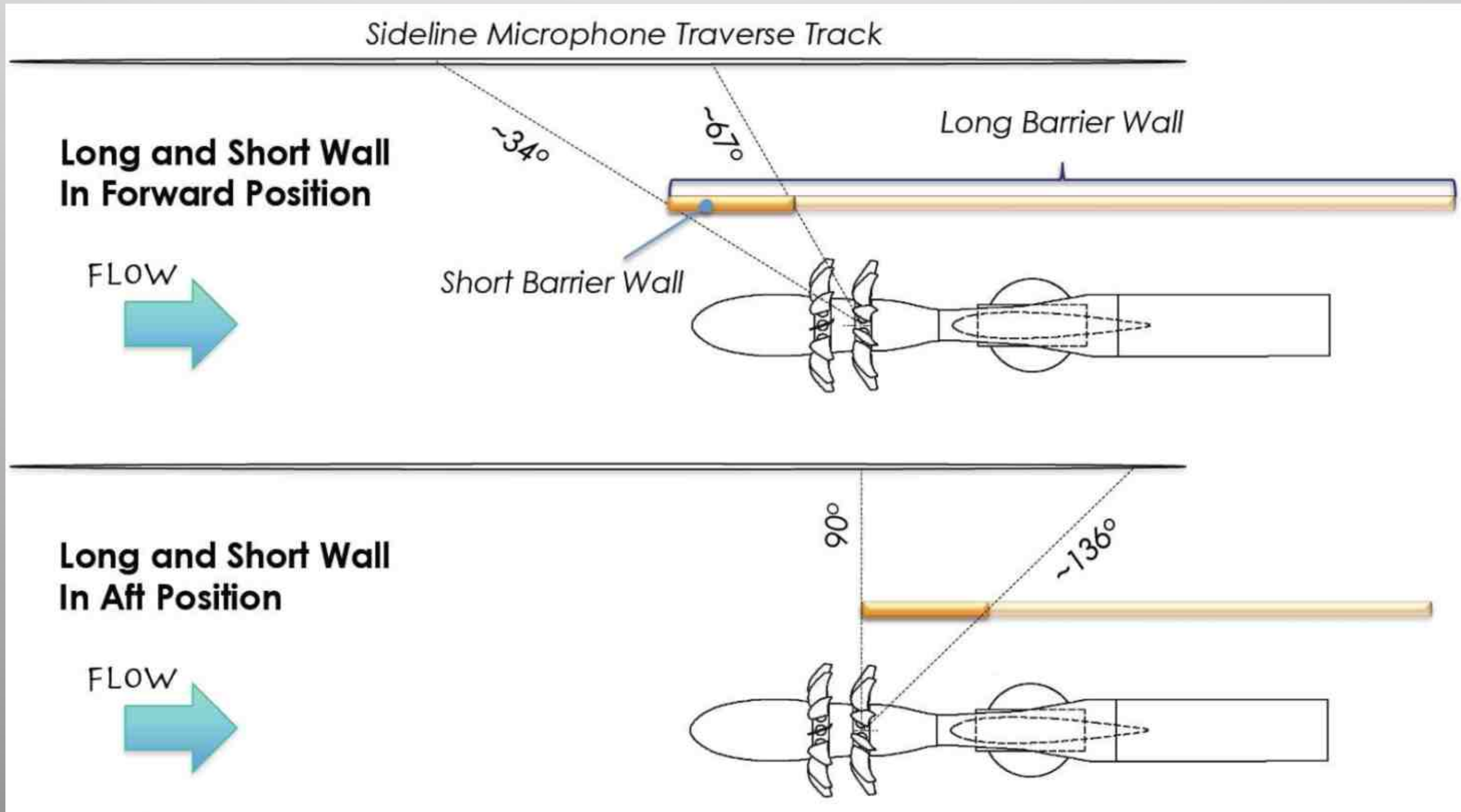


The location of peak noise level in the **phased array** map changes in the presence of the CFMI pylon indicating a change in the relative strength of sources.

The **Pressure Sensitive Paint** measurements show phase locked static pressure on the surface of the rotating blade.

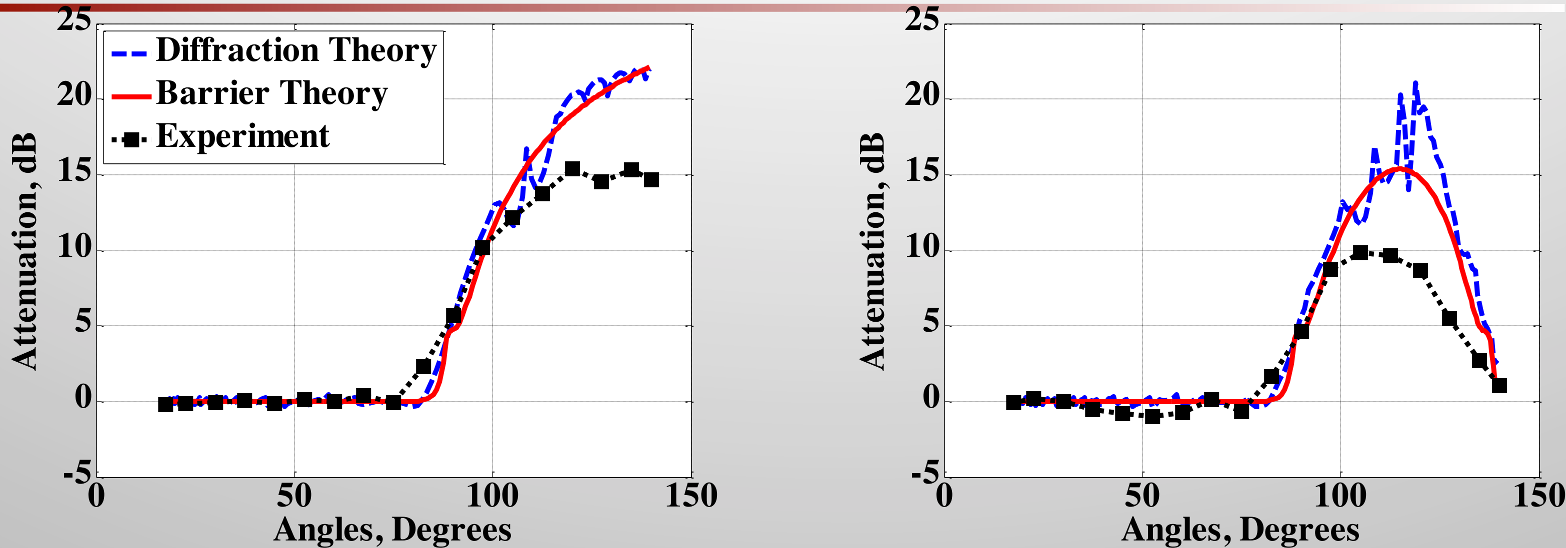
Test Geometry

1. Rotor sound should be unaffected by the wall
2. Should be useful for validation of prediction methods
3. Useful for estimation of noise reduction in system level studies



Shielding Experiment: Realistic Source, Simplified Shield

Simplified Shield Results



- **Up to 10 dB OASPL peak attenuation with short barrier**
  - **Enough to meet noise goals?**

- **Simplified prediction methods over-predict shielding: advanced methods needed**
  - **Source distribution may be complicated**

Stephens, David and Envia, Edmane, "Acoustic Shielding for a Model Scale Counter-rotation Open Rotor," AIAA 2011-2940, 17th AIAA/CEAS Aeroacoustics Conference, Portland, Oregon, June 2011.

Berton, Jeffery J., "Empennage Noise Shielding Benefits for an Open Rotor Transport," AIAA 2011-2764, 17th AIAA/CEAS Aeroacoustics Conference, Portland, Oregon, June 2011.

Prediction of Open Rotor Acoustic Shielding Benefits

PROBLEM

- Prediction and optimization of canonical shielding configurations for advanced low-noise open rotor installations

OBJECTIVE

Assess capability of LINPROP code for predicting acoustic benefits of open rotor tone noise shielding by airframe components such as wing or U-tail

- Realistic three-dimensional open rotor geometries and operating conditions
- Representative canonical shielding configurations

APPROACH

Assess accuracy of LINPROP code using wind tunnel acoustic test data

- F31/A31 sideline acoustic data for free-field and shielded configurations
- 3D aerodynamic simulation of unsteady loading on F31/A31 blade rows
- 3D acoustic field calculations for configurations of interest using LINPROP code

A Conceptual Open Rotor Installation Offering Potential Acoustic Shielding Benefits by the U-Tail

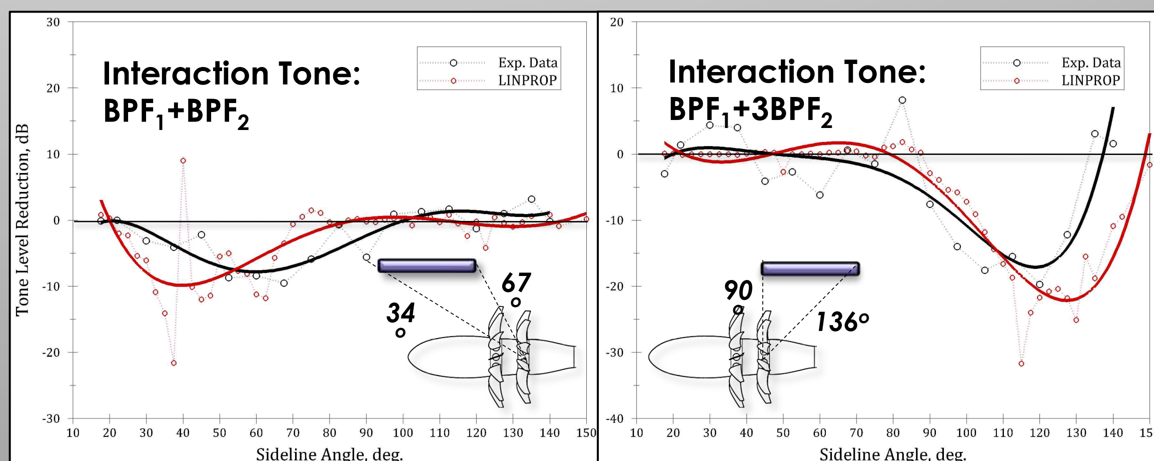
RESULTS

Technical Progress:

- Demonstrated fairly good agreement between LINPROP predictions and measured acoustic benefits of finite shields representative of U-Tail installations

Paper, Presentation, etc.:

Presented highlights at the 2012 Annual Fundamental Aeronautics Meeting in Cleveland, OH in March



Predicted and Measured Acoustic Shielding Benefits (i.e., Reduction in Tone SPL) for Two Canonical Shielding Configurations for F31/A31 Open Rotor

POC: Ed Envia, NASA

Outlook

- The progress in source noise reduction has been remarkable.

- System analysis (TRL 4) has shown promise for new aircraft designs.

- Next steps are installation effects.

Abstract

The Open Rotor is a modern version of the UnDucted Fan (UDF) that was flight tested in the late 1980's through a partnership between NASA and General Electric (GE). Tests were conducted in the 9'x15' Low Speed Wind Tunnel and the 8'x6' Supersonic Wind Tunnel starting in late 2009 and completed in early 2012. Aerodynamic and acoustic data were obtained for takeoff, approach and cruise simulations. GE was the primary partner, but other organizations were involved such as Boeing and Airbus who provided additional hardware for fuselage simulations. This test campaign provided the acoustic and performance characteristics for modern open rotor blades designs.

NASA and GE conducted joint systems analysis to evaluate how well new blade designs would perform on a B737 class aircraft, and compared the results to an advanced higher bypass ratio turbofan.

Acoustic shielding experiments were performed at NASA GRC and Boeing LSAF facilities to provide data for noise estimates of unconventional aircraft configurations with Open Rotor propulsion systems.

The work was sponsored by NASA's aeronautics programs, including the Subsonic Fixed Wing (SFW) and the Environmentally Responsible Aviation (ERA) projects.